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Understanding Reservoir-Induced Seismicity*

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Abstract: We review the monitoring and study of reservoir-induced seismicity (RIS) in the half past century, and analyze the major problems in RIS study. We suggest that it will be the key work in the future to further accumulate data, determine the major influence factors on RIS, study RIS mechanism by means of observational and experimental methods, and develop effective prediction techniques of RIS.

Key words: reservoir-induced seismicity; factor of inducing earthquake; mechanism; prediction

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0 Introduction

The human race began to construct the reservoirs with the dam height≥100 m in the early 20th century. According to statistics in 1973, there were about 326 reservoirs with the dam height≥100 m in the world, 265 finished and 61 constructing. In 2003, there were about 670 reservoirs with the dam height≥100 m in the world, including 155 huge reservoirs with the dam height≥150 m (Mao, 2007).

The reservoir-induced seismicity (RIS) began to attract the researchers' attention since the M4.7 earthquake at Marathon Reservoir in Greece in 1938 and the M4.6 earthquake at Lake Mead in USA in 1939 (Ding, 1989; Gupta, 1992). The dam height and capacity of Marathon Reservoir are 67 m and 0.67×10^8 m^3, and those of Lake Mead are 221 m and 375×10^8 m^3.

According to Gupta et al (1972), RIS was for the first time proposed by Carder in 1945 for Lake Mead. Since then, a number of RIS cases have been cited by many researchers.

By the early 1970's, only over a dozen RIS cases were reported (Gupta, 1992).

Up to 1986, the statistics of 33 770 reservoirs from 29 countries including China gave 116 reservoirs which induced earthquake (Li, 1999).

Up to the initial 21th century, more than 140 RIS cases had been determined in the world (Yao, 2006), including 4 cases of M≥6, 36 cases of M4.5-5.9, 43 cases of M3.0-4.4, and 51 cases of M<3.0. These RIS cases are distributed in more than 30 countries and more than 10 of them occurred in China. And RIS phenomenon has occurred in Three-Gorge Reservoir, Hubei, China since its water level reached 135 m (Yao, 2006).

The M6.1 earthquake that occurred at Xinfengjiang Reservoir of Guangdong on 19 March 1962 is considered as the first RIS case of M≥6 in the world (Ding, 1989). During 5 years after the Xinfengjiang reservoir earthquake, three other earthquakes of M≥6 occurred in Kariba Reservoir in Zambia-Zimbabwee Border area, Kremasta Reservoir in Greece, and Koyna Reservoir in India. These earthquakes caused serious damage and economic losses. Therefore, since the mid-20th century after 4 RIS cases of M≥6, much more attention has been paid to the RIS study.

By the efforts of the researchers in lots of countries during the past half century, some development of RIS study has been made.

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1 RIS Monitoring and Study during the Past Half Century

1.1 RIS Monitoring

The earliest monitoring of RIS began in the Lake Mead area in 1938. Since the 1950's, some countries have carried out RIS monitoring to determine the kinematics and dynamics parameters of RIS, and also to study the relationship among earthquake, water filling and geology. Besides the earthquake monitoring, the earthquake stress dropping survey and hydro-pressure-breaking stress survey were carried out at Monticello Reservoir of USA during 1978—1980 by Fletcher et al (1983) and Rajendran et al (1992). Based on the relationship between seismic spatial-temporal distribution and hydro-chemical composition, Talwani et al predicted two earthquakes of M2—4 (Hu, 1983).

The Chinese RIS monitoring began after the Xinfengjiang, Guangdong, M6.1 earthquake which occurred at the vicinity of the Xinfengjiang Reservoir dam on 19 March 1962. After the occurrence of the Xinfengjiang earthquake, the station network was set up in the Xinfengjiang Reservoir area, which was renewed in the early 1980's and still works today. The Chinese Hydro-construction Design Code regulated that the RIS study and earthquake monitoring should be carried out in the high-dam construction area in which there are great probability of reservoir-induced earthquakes, complex geological condition and active faults.

In the past 40 years, the RIS monitoring in China had experienced 4 periods of development as follows:

The 1st Period: it was a manual acting period. RIS monitoring was carried out at Nanshui Reservoir of Guangdong in the 1960's, Dahua Reservoir of Guangxi in the 1980's, Yantan Reservoir of Guangxi and Tongjiezi Reservoir of Sichuan in the 1990's.

The 2nd Period: it was a period of non-special remote monitoring model, and teleseismic technique was introduced to RIS monitoring from natural earthquake observation in the 1970's and 1990's at Longyangxia Reservoir of Qinghai, Danjiangkou Reservoir of Hubei, Manwan Reservoir of Yunnan, Shuikou Reservoir of Fujian, etc.

The 3rd Period: it was a period of special teleseismic observation network. For example, in Seismic Monitoring Network Study Program of Ertan, Sichuan, Reservoir, the broadband remote equipment was developed and 5—9 stations were designed in the system, and the techniques were applied to the monitoring at Geyanhe Reservoir of Hubei, Longyangxia Reservoir of Qinghai, etc.

The 4th Period: it is a period of comprehensive observation and digital teleseismic observation. The related techniques were applied to Three-Gorges, Hubei, Reservoir-Induced Seismicity Monitoring System, which was composed of seismology, deformation and underground fluid monitoring techniques. This observation model has also been applied to the Xinuodu, Xiangjiaba, and Baihetan reservoirs.

1.2 RIS Study

With the development of RIS monitoring, a lot of basic studies are also carried out. These studies include special studies for some reservoir, the investigations of RIS cases, and the study for characteristics and genesis of RIS, etc.

(1) RIS case reports and special studies for some reservoirs

Up to now there have been papers specially studying some reservoirs, such as Bhatsa Dam, Osman Sagar Reservoir, Bhakra Dam and Koyna Dam in India, Lake Mead, Oroville Reservoir, Clark Hill Reservoir, Lake Keowee, Lake Jocassee and Manticello Reservoir in USA, Lake Kariba in Zambia-Zimbabwe, Lake Kremasta and Lake Marathon in Greece, Lake Benmore in New Zealand, Camo do Cajuru Reservoir (Porto Colombia dam and Volta Grande Dam) and Marimbondo Reservoir in Brazil, Toktogul Reservoir in Tadzhikistan, Aswan Dam in Egypt, and 28 reservoirs in China (the Xinfengjiang and Nanshui reservoirs of Guangdong, the Dahua and Yantan reservoirs of Guangxi, the Canwo reservoir of Liaoning, the Danjiangkou, Qianjin, Three-Gorges, Panjiakou, and Geyanhe reservoirs of Hubei, the Shiquan reservoir of Shanxi, the Manwan and

Dachaoshan reservoirs of Yunnan, the Shuikou reservoir of Fujian, the Tongjiezi, Daqiao and Ertan reservoirs of Sichuan, the Zhelin reservoir of Jiangxi, the Dongjiang and Huangshi reservoirs of Hunan, the Wujiangdu, Yinzidu and Dongfeng reservoirs of Guizhou, the Wuxijiang and Shanxi reservoirs of Zhejiang, the Kezier reservoir of Xinjiang, the Longyangxia reservoir of Qinghai, the Jiangkou reservoir of Chongqing).

Generally, there are more study materials for the reservoirs with large scale or where the earthquake ($M \geqslant 4.0$) has occurred. They are Xinfengjiang Reservoir, Danjiangkou Reservoir, Shuikou Reservoir, Sanxia Reservoir, Lake Mead, Lake Kariba, Koyna Dam, Oroville Reservoir, Lake Jocassee, Manticello Reservoir, Nureck Reservoir, etc.

These papers studied the characteristics of post-impoundment seismicity and its relationship to water level. The detailed geological data of reservoirs are few comparatively.

(2) Synthetic studies on RIS genesis and mechanism

Besides the studies on a special reservoir, some synthetic studies on the characteristics of RIS genesis and mechanism have also been published. The representations are as follows:

Reservoir-Induced Earthquakes in China: it was published by STATE SEISMOLOGICAL BUREAU OF CHINA in 1983, in which 22 articles were compiled, and the articles studied 8 Chinese reservoirs, including Xinfengjiang Reservoir, Danjiangkou Reservoir, Zhelin Reservoir, Qianjin Reservoir, Nanshui Reservoir, Wujiangdu Reservoir, Wuxijiang Reservoir and Huangshi Reservoir. The geological conditions, style division, genesis and mechanism of the RIS cases were also analyzed in the book.

Reservoir-Induced Earthquakes: it was written by Ding Yuanzhang in 1989, in which 41 RIS cases were introduced, including 7 cases in China, 13 in Asia, 10 in Europe, 4 in Africa, 7 in North America, 4 in Australia, and 3 cases of seismicity decreasing after impounding.

Reservoir-Induced Earthquakes: it was authored by H. K. Gupta and published in 1992, in which 41 RIS cases were introduced, and RIS characteristics and mechanism were also discussed.

Apart from above books, some comprehensive articles (Hubbert et al, 1959; Rothe, 1968; Gupta et al, 1972; Kisslinger, 1976; Simpson et al, 1976; Stuart-Alexander et al, 1976; Castle et al, 1980; Baecher et al, 1982; Gupta et al, 1986; Chen et al, 1988; Roeloffs, 1988; Assumpcao et al, 2002) on RIS have also been published.

2 Problems in RIS Study

Although much progress has been achieved in RIS study, and lots of knowledge on RIS has also been obtained, some important problems still exist in RIS study.

2.1 RIS study has been in the initial period limited by data accumulation

In 1980, Allen pointed out that we knew few about the mechanics why RIS occurs and can not be sure which reservoirs earthquake may occur (Hu, 1981).

In 1983, a section on induced seismicity in a publication of the US National Academy of Sciences concerned the dam safety, stated that there was a question of whether a reservoir may induce earthquakes. To date there is no universally accepted proof that this can occur, but it is a possibility that consideration should be given (Gupta, 1992).

Hu (1983) pointed out: "although the RIS study has got some progresses recently, it is still in the period of data accumulation. More work should be carried out in the monitoring and study of RIS, especially the accumulation of abundant and accurate data, which is very important to the development of RIS research."

Gupta (1992) stated: "the phenomenon of RIS is not yet fully understood. The frequently asked questions are how to assess the potentiality of reservoir-induced earthquakes at a given reservoir site, and what the magnitude of the largest induced earthquake would be. During the past three decades, some knowledge on RIS had been gained, but there still are lots more on RIS need to be studied."

Yi (2003) stated that after some damage reservoir earthquakes occurred in the 1960's, the reservoir induced earthquakes began to be studied in the world. The studies during this period were mainly centered in geology, seismology, physical mechanism and techniques for the risk evaluation and prediction of RIS. But since the late 1980's, RIS study has nearly stopped and few articles have been published.

Chen (2004) concluded that the RIS was a complex problem, which belonged to a new item of earthquake study. Up to now, RIS study is still preliminary in the world, and the reservoir induced earthquake can not be predicted accurately yet today.

2.2 Knowledge of induced factors of reservoir earthquake and their relationship is not consistent

Sun (1996) stated that the RIS was the result of many factors. She gave the statistic analysis to 22 states of 6 factors, which included water depth, capacity, stress regime, fault activity, petrology and historical seismicity.

Li (1999) stated that water filling could not only induce earthquakes, but also decreased seismicity in certain geological conditions. So it is necessary to study these phenomena. However, it is difficult to investigate the detailed geological environment of a reservoir, so it should be careful to analyze the geological conditions around a reservoir in order to search the characteristic geology of RIS.

Although it has been generally accepted that RIS is related with the geological structure of reservoirs, Yi (2003) concluded that the numerous studies on geological environments of RIS were summarized in a large regional scale, and mainly in regional fault dynamics, rock petrology, tectonic stress regime and seismicity, but some basic questions were still remained unanswered. Therefore, more attention should be paid to the synthetic studies on the characters of reservoir construction and geological structures and environments in order to find major factors of inducing earthquakes from the reservoir construction characters, strata feature, geological structures and tectonics, underground water and stress conditions.

2.3 RIS mechanism is still in argument

Because there was no consistent knowledge on the occurrence and development of RIS during the past half century, the genesis and mechanism of RIS had been in argument.

Yu (1984) stated that different suggestions on RIS genesis were concluded based on regional geological background, hydro-geological condition of reservoir, water load and earthquake activity, etc.

Li (1984) concluded that the different development tendency of RIS should be evaluated by different ideas of RIS genesis. The occurrence and development of RIS should be dependent firstly on geological conditions and strain energy accumulation, secondly on water load pressure and pore-pressure and other factors including earth rotation.

According to Yi (2003), there were different opinions on RIS mechanism. The interactions between reservoir and geological environments should be very complex. The water load, pore-pressure, softening and lubricating of fault plane under the action of underground water should influence the occurrence of RIS, but which one should be the key role to RIS is still not answered up to now.

2.4 There are not effective RIS prediction techniques up to now

After RIS problem appeared, the RIS prediction became a question needed to be solved. Up to now, a lot of efforts have been made in the search of long-period prediction technique.

Talwani (1997) pointed out that despite the progress attained in explaining the mechanism of RIS, it was not possible to predict the occurrence of induced seismicity of a future reservoir, because of the practical difficulties in accurately mapping geological conditions beneath the reservoir. And key parameters such as in situ stresses, permeability of the rock masses and geometry of fracture system could not be accurately determined.

According to Yi (2003), the main researches on RIS prediction were as follows:

In 1979, Hu Yuliang suggested the possibility of evaluating RIS probability by means of the study on rock petrology and its permeating condition, and geological stability.

In 1979 and 1982, Packer and Baecher suggested the probability method of RIS prediction, which used the data of water depth, capacity, stresses regime, fault activity, petrology in the reservoir area.

In 1984, Hu Yuliang stated that the geological background and tectonic conditions of RIS were similar to those of nature earthquakes, therefore, the study idea and method, and prediction experience of nature earthquakes could be used to the prediction of RIS. In addition, he suggested that reservoir action and hydrogeology should be considered in RIS prediction.

In 1989, Chang Baoqi advanced the fuzzy judge theory of RIS.

In 1995, Huang Runqiu and Xu Qiang advanced the neural network model of RIS prediction.

In 1995, Wang Yongxi put forward the multi-factor prediction method of RIS based on rock structure and vertical hydro-geological belt division.

In 2000, Xia Qifa put forward the program and method of RIS risk evaluation based on engineering geology, which is the synthetic study of regional engineering geology, tectonics, hydro-geology, and seismology.

In 2001, Zhang Qiuwen summarized the RIS prediction methods into two kinds: certain prediction and uncertain prediction.

Based on the studies above mentioned, Yi (2003) stated that RIS study was still in the period of data accumulation and cases comparison, and there still were not good theory and method to predict RIS risk.

2.5 Some basic relationships need to be studied

Although lots of knowledge on genesis and mechanism of RIS has been obtained, they are different in the relationship among RIS activity, water depth (or dam height), capacity, stress regime, fault activity, petrology, and historic seismicity.

(1) With regard to the relationship between RIS activity and reservoir scale, there are two opposite opinions. Some researchers considered that there was a positive relation between RIS activity and capacity or dam height (Hu, 1983; Li, 1999), but others also suggested the opposite cases (Li, 1984); they considered that there was not significant relationship between RIS activity and capacity or dam height (Chen, 2004).

(2) With regard to the relationship between RIS activity and water level variation, Li (1999) and Yu (1984) considered that the relationship was complicated. Ding (1989), Chen (2004), and Yang et al. (2003) suggested that post-impoundment seismicity increased during water level uprising, and the maximum frequency and magnitude of earthquakes occurred at peak water level in some RIS cases. Li (1984) concluded that the relationship between RIS activity and water level variation was more complex after initial impoundment or main shock of RIS.

(3) The relationship between RIS activity and natural seismicity background is still not clear now. It is generally accepted that the reservoir induced earthquake usually occurred at the reservoirs which were constructed in the low-seismicity area (Ding, 1989; Chen, 2004). It was also concluded that there was no obvious positive relationship between RIS activity and regional natural seismicity (Wang, 2002; Marcelo, 2002), and the probability of RIS occurrence did not depend on the regional basic seismic intensity in the reservoir area (Hu, 1983).

(4) With regard to the relationship between RIS activity and petrology, there are the following opinions:

The RIS is related with metamorphic rocks (Stuart-Alexander, 1979).

Most of the RIS cases occurred in the carbonate rock area (Xia, 1984; Ding, 1989; Yi, 2003).

The RIS probability in magnetic rock area is bigger than that in metamorphic rock area (Li, 1999).

Only a few RIS cases occurred in the volcanic rock area (Wang, 2002). But of the 19 RIS cases in Brazil, the strata exposed in the areas of 11 RIS cases are basalt and granite, 6 cases occurred in the area of metamorphic rock and 2 in the area of sediment rock (Marcelo, 2002).

It was also suggested that RIS usually occurred in the area in which rock was fractured, or karst was developed, where the water permeation of the rocks should be strong (Li, 1984).

(5) With regard to the relationship between RIS

activity and tectonic environment, it was generally accepted that RIS was related with the geological environments of reservoir (Gupta, 1972; Li, 1999), and the existence of pre-existed faults was very important to the occurrence of reservoir-induced earthquake (Rothe, 1973; Yu, 1984; Yi, 2003).

Hu (1984), Li (1984), Yu (1984), Ding (1989), Li (1999), and Wang (2002) suggested that RIS was related with neo-tectonics, especially with the active faults including the Holocene active faults. But Stuart-Alexander (1979) and Xia (1984) also concluded that the existence and activity of faults were not important to the occurrence of reservoir-induced earthquake.

RIS was related with the existence of large fault in a reservoir area (Wang, 2002; Li, 1999). But the RIS was also related with small fault (Ding, 1989; Keith et al, 1982).

It was generally accepted that RIS usually occurred in the tension stress environment. But someone suggested that RIS was related with shearing zone (Baecher, 1982), and someone concluded that RIS also occurred in compressing areas (Li, 1984; Yu, 1984).

(6) With regard to the relationship between RIS activity and fault property, it was generally accepted that reservoir-induced earthquake more easily occurred along normal fault than along reverse fault or strike-slip fault (Yi, 2003). Li (1999), Simpson (1976), and Wang (2002) also concluded that reservoir-induced earthquake should easily occur along normal fault and strike-slip fault. While Yu (1984) suggested that reservoir-induced earthquake should be easy to occur on tension fault and shearing-tension. Castle (1980) and Anglin (1985) pointed out that the earthquakes at some reservoirs such as Monticello Reservoir, Manic3 Reservoir, LG2 and LG3 reservoirs, occurred along the reverse fault or in reverse faulting environment. Tsengwen, Taiwan, China reservoir was constructed on a reverse fault, its post-impoundment seismicity decreased. Baecher et al (1982) suggested that the shearing stress regime was more prone to the occurrence of reservoir-induced earthquake than tension stress and compressing regimes.

3 Conclusions

The RIS question was put forward because of the earthquake of M4.7 at Marathon Reservoir of Greece in 1938 and the earthquake of M4.6 at Lake Mead of USA in 1939, and was stressed by 4 earthquakes of M>6.0 after that. In the past half century, lots of RIS monitoring and study had been carried out and much progress had been achieved. However, a lot of work needs to be done in the future, including the accumulation of RIS case data, the studies of factors of inducing reservoir earthquake, the determination of major factors, the mechanism study of RIS based on observation and experiment, and the development of effective RIS prediction techniques.

References:

Anglin F M, Buchbinder G G R. 1985. Induced seismicity at the LG3 Reservoir, James Bay, Quebec, Canada [J]. BSSA, 75 (4): 1067—1076.

Assumpcao M, Marza V, Barros L, et al. 2002. Reservoir-induced seismicity in Brazil [J]. Pure and Applied Geophysics, 159: 597—617.

Baecher B G, Keeney R L. 1982. Statistical examination of reservoir induced seismicity [J]. BSSA, 72 (2): 553—569.

Castle R O, Clark M M, Grantz A, et al. 1980. Tectonic state, its significance and characterization in the assessment of seismic effects associated with reservoir impounding [J]. Eng. Geol., 15: 53—99.

Chen G X. 2004. Mechanism and examples of earthquake induced by reservoir [J]. Yunnan Geology, 23 (2): 266—269. (in Chinese)

Chen L, Talwani P. 1998. Reservoir-induced seismicity in China [J]. Pure and Applied Geophysics, 153: 133—149.

Ding Y Z. 1989. Reservoir-induced seismicity [M]. Beijing: Seismological Press. (in Chinese)

Fletcher J B, Boatwright J, Joyner W B. 1983. Depth dependence of source parameters at Monticello, South Carolina [J]. BSSA, 73 (6A): 1735—1751.

Gupta H K, Rajendran K. 1986. Large artificial water reservoirs in the vicinity of the Himalayan Foothill and reservoir-induced seismicity [J]. BSSA, 76 (1): 205—215.

Gupta H K, Rastogi B K, Narain H. 1972. Common features of reservoir associated seismic activity [J]. BSSA, 62 (2): 481—492.

Gupta H K. 1992. Reservoir-Induced Earthquakes, Netherlands [M]. Amsterdam: Elsevier Science Publishers.

Hu Y L, 1981. Research on the reservoir induced earthquake in South America [J]. Translated Works of Seismogeology, 3 (4): 41—43 (in Chinese).

Hu Y L, 1983. Progress on reservoir induced seismicity study [J]. Seismogeology Translation Collection, (3): 1—9. (in Chinese)

Hubbert M K, Rubey W. 1959. Role of fluid pressure in mechanics of overthrust faulting: Pts. I and II [J]. Geol. Soc. Am. Bull., 70: 115—205.

Keith C M, Simpson D W, Soboleva O V, et al. 1982. Induced seismicity and style of deformation at Nurek Reservoir, Tadjik SSR [J]. JGR, 87 (B6): 3509—4624.

Kisslinger C. 1976. A review of theories of mechanism of induced seismicity [J]. Eng. Geol., 10: 85—98.

Li H H. 1999. The preliminary discussion of reservoir earthquake and environment [J]. Journal of North China Institute of Water Conservancy and Hydroelectric Power, (1): 32—36. (in Chinese)

Li Z W. 1984. Discussion on some questions about the reservoir induced earthquake [C] // Institute of Earthquake Science, China Earthquake Administration. Reservoir induced seismicity in China. Beijing: Seismological Press, 42—49. (in Chinese)

Mao Y P, Ai Y P, Shao D S, et al. 2007. Study on seismic safety of reservoir [J]. Journal of Seismological Research, 30 (3): 253—259. (in Chinese)

Rajendran K, Talwani P. 1992. The role of elastic, undrained, and drained responses in triggering earthquakes at Monticello Reservoir, South Carolina [J]. BSSA, 82 (4): 1867—1888.

Roeloffs E A. 1988. Fault stability changes induced beneath a reservoir with cyclic variations in water level [J]. JGR, 93 (B3): 2107—2124.

Rothe J B. 1968. Fill a lake, start an earthquake [J]. New Sci., 39: 75—78.

Rothe J P. 1973. A Geophysics report [M] // White G F, Ackermann W C, Worthington E B. Man-made Lakes: Their problems and environmental effects (Geophysical Monograph 17). Washington, D C: American Geophysical Union, 441—454.

Simpson D W. 1976. Seismicity changes associated with reservoir loading [J]. Eng. Geol., 10: 123—150.

Stuart-Alexander D E, Mark R K. 1976. Impoundment-induced seismicity associated with large reservoirs [R]. U. S. Geological Survey Open File Report 770.

Sun J X. 1996. Study of the reservoir induced earthquake prediction method [J]. Seismology and geology, 18 (4): 421—426 (in Chinese).

Talwani P. 1997. On the nature of reservoir induced seismicity [J]. Pure appl. geophys, 150: 473—492.

Wang J, Hu X Z. 2002. Analysis of induced earthquake possibility in Baishi reservoir of Liaoning Province [J]. Jilin Water Resources, (6): 30—32. (in Chinese)

Xia Q F. 1984. Preliminary discussion of the Geological classification of reservoir induced earthquake [C] // Institute of Earthquake Science, China Earthquake Administration. Reservoir induced seismicity in China. Beijing: Seismological Press, 8—14 (in Chinese)

Yao Y S. 2006. Introduction of the program Monitoring and Studies for Reservoir induced Earthquakes in the Three Gorge Reservoir [J]. Recent Developments in World Seismology, (9): 67—69. (in Chinese)

Yi L X, Che Y T, Wang G C. 2003. Retrospection and prospect of the research on reservoir induced seismicity [J]. South China Journal of Seismology, 23 (1): 28—37. (in Chinese)

Yu P Q. 1984. Discussion on the genesis of reservoir induced earthquakes [C] // Institute of Earthquake Science, China Earthquake Administration. Reservoir Induced Seismicity in China. Beijing: Seismological Press, 30—35. (in Chinese)

对水库诱发地震研究的几点认识

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摘要：回顾了过去半个多世纪水库诱发地震观测与研究的进展，分析了当前水库诱发地震研究面临的主要问题，认为进一步积累资料、确定水库诱发地震的关键影响因子、采用观测和实验手段研究水库诱发地震机理，并在此基础上研究有效的水库诱发地震预测技术，是今后水库诱发地震研究的重点。

关键词：水库诱发地震活动；影响因子；机制；预测